EIC Detector R&D

Progress Report and Proposal

Project ID: eRD3

Project Name: Design and assembly of fast and lightweight barrel and forward tracking prototype systems for an EIC

Period Reported: January 01, 2016 – June 30, 2016 (Status) / October 01, 2016 - September 30, 2017 (Proposal)

Project Leaders:
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Date: June 15, 2016

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Introduction

This report concentrates on a dedicated tracking system based on micro-pattern detectors, which focuses on the design and development of fast and lightweight detectors, ideally suited for a future EIC experiment. The science case and basic detector specifications have been documented in a White paper report [1]. The micro-pattern tracking detector system consists of:

- Barrel tracking system based on MicroMegas detectors manufactured as six cylindrical shell elements.
- Rear / Forward tracking system based on triple-GEM detectors manufactured as planar segments of three layers in the rear and forward directions.

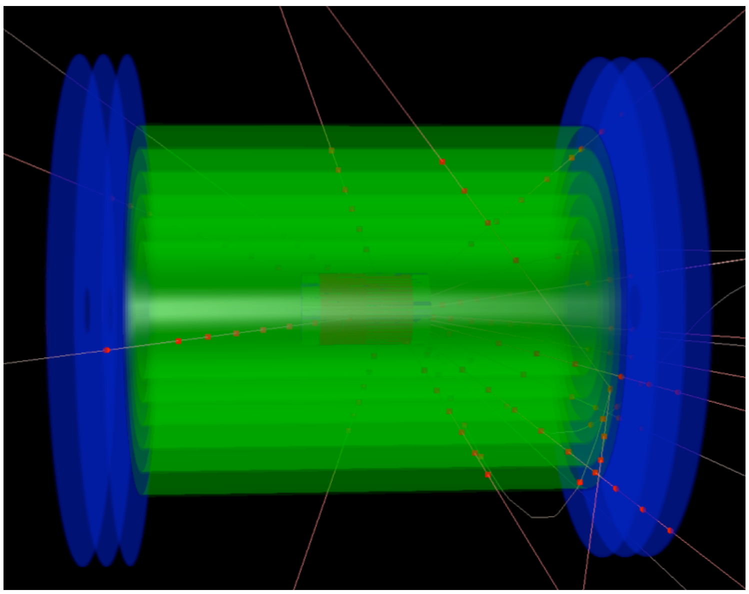

Figure 1: *GEANT simulation of barrel (green) and rear / forward (blue) tracking systems for an EIC detector.*

Figure 1 shows a 3D view of a GEANT simulation for a barrel and rear / forward tracking system which has been initiated by the R&D program documented in this report. The R&D effort focuses on the following areas:

- Design and assembly of large cylindrical MicroMegas detector elements and planar triple-GEM detectors,
- Test and characterization of MicroMegas and triple-GEM prototype detectors,
- Design and test of a new chip readout system employing the CLAS12 DREAM-chip development, ideally suited for micro-pattern detectors,
- Utilization of light-weight materials,
- Development and commercial fabrication of various critical detector elements and

- European/US collaborative effort on EIC detector development (CEA Saclay and Temple University).

This report provides an overview of various R&D activities in FY16 both in the barrel and rear / forward directions following the last meeting of the EIC R&D committee in January 2016.
The allocation of funds of $104k for FY16 as stated in the award letter from August 2015 became only available at Temple University in spring 2015. As a result various orders have only recently been placed which will be discussed in detail below. A new postdoc candidate was identified in December 2015. The starting date was delayed to May 2016 with the delay of the FY16 funds. Our new postdoc, Dr. Amilkar Quintero, completed his Ph.D. thesis work with the STAR experiment at RHIC on the STAR Heavy Flavor Tracker at Kent State University. He has a lot of experience with tracking software and has prior experience with micro-pattern detectors at CERN while completing a Master's Degree at Florida Institute of Technology with Professor Marcus Hohlmann, our collaborator of the EIC eRD6 program. The bulk of the EIC R&D program was so far carried on by Dr. Matt Posik besides his physics analysis efforts at the STAR experiment. His appointment at Temple University is now shared between the College of Science and Technology at Temple University and the EIC R&D sub-contract. Dr. Amilkar Quintero will be trained by Dr. Matt Posik and will share his commitment between the EIC R&D program and the physics analysis program of high-energy polarized p+p physics by Professor Bernd Surrow at RHIC covered by his DOE Nuclear Physics base grant. This allows continued progress on both the EIC R&D program supported by the EIC eRD3 sub-contract and the physics analysis program covered by a DOE Nuclear Physics base grant. It is essential to expose a beginning postdoc to both hardware and physics analysis activities for future career opportunities. The College of Science and Technology has now hired a new mechanical engineer, Mr. James Wilhelmi, in support of Nuclear Physics research activities at Temple University. We do consider this and the local new machine shop an outstanding resource for our detector development work.

It should be emphasized that our R&D program is a dedicated development of various elements for a future EIC tracking detector system. It is the only R&D program which provides an alternative barrel tracking system besides a TPC R&D program. The generic R&D program is expected to be completed by 2018. It is then planned to enter a phase of targeted EIC detector design work focusing on specific prototyping assembly and testing activities in close collaboration with the Florida Institute of Technology and the University of Virginia in preparation of a Technical Design Report required in part for the DOE Critical Decision process. This step will be carried out in general in collaboration with the EIC eRD6 program. It is planned to fully merge both efforts with the completion of the generic R&D program. More details are provided in a common eRD3/6 document.

Over this time period we have had good success in promoting our EIC R&D research efforts. A presentation is planned at the IEEE conference in fall 2016 based on the status of our R&D program and the recent NIM publication [2]. The International Advisory Committee of the International Micro-Pattern Gas Detector conference series asked the eRD3/6 R&D group through Dr. Klaus Dehmelt and Professor Bernd Surrow about the possibility to host the International

Micro-Pattern Gas Detector conference in 2017 (MPGD 2017) at Temple University. A presentation was made to the advisory committee during a recent RD51 meeting at CERN on Monday, June 6 together with one other competing proposal to host the MPGD 2017 conference. On Tuesday, June 14, we were informed that the International Advisory Committee decided in favor of Temple University and participating institutions of eRD3/6 to host the MPGD 2017 conference. We do consider the interest by the International Advisory Committee for the eRD3/6 groups to host the next International Micro-Pattern Gas Detector conference as a strong recognition of our R&D program [2, 3, 4] on an international level.

Forward Triple-GEM R&D Program

Past

What was planned for this period?

Over the time period of 01/16 to 06/16, we had planned to carry out R&D efforts in several areas:

1. Finalize an EIC GEM foil design, in collaboration with eRD6, that will serve as a common GEM foil used in three unique forward/rear triple-GEM tracking detectors from three different groups (Temple University, Florida Institute of Technology, and University of Virginia).

2. Upgrade our current GEM CCD scanner, which quantifies the geometrical properties of GEM foils, to accommodate large area GEM foils (> 50 cm long).

3. Construction of 40 cm x 40 cm triple-GEM detectors using Tech-Etch produced single-mask foils, HV foils and 2D readout foils. These detectors will allow us to

    - Investigate new methods of separating the foil layers via spacer rings, in an effort to further reduce the material budget of the detector.
    - Characterize the detector gains via cosmic rays and X-rays.
    - Study clustering schemes using our already developed and commissioned CAEN HV system.

5. Construction of 10 cm x 10 cm triple-GEM detectors using Tech-Etch produced single-mask GEM foils.

6. Further test of implementing the DREAM chip with triple-GEM detectors, with the ultimate goal of having the EIC triple-GEM detectors use the DREAM chips.

7. Commercialization of large GEM foils and other components.

What was achieved?

Since the last update in January 2016, there has been progress made in several areas:

1) EIC GEM Foil Design

In collaboration with eRD6, the three institutions (Florida Institute of Technology, Temple University and University of Virginia) have finalized the design of an EIC GEM foil. This common design will be used to produce three unique triple-GEM detectors, with each of the three institutions using different assembly and readout techniques. More details of the assembly and readout differences between the institutions can be found in [4] and in the common eRD3 / eRD6 report. This effort is considered beyond the current generic R&D program and enters the phase of targeted prototyping design work.

In addition to the production of full fledged EIC GEM foils (~ 1 meter long), we feel that it would be advantageous to proportionally scale the EIC GEM foil design down such that the foils measure somewhere on the order of 50 cm long. The design of such a scaled-down version is nearly completed. These dimensions meet the dimensions required by the EIC BEAST detector design.

2) GEM CCD Scanner

It is vital that our GEM CCD scanner can accommodate larger GEM foils if we would like to measure the GEM foil's geometrical properties. Our current setup is not suitable to scan foils even of the size of our current available large foils of 40 cm x 40 cm. The current setup was meant to scan foils only up to 10 cm x 10 cm. Our current CCD scanner is unable to measure foils that are 50 cm long. To allow the scanning of larger area GEM foils, two upgrade scenarios were considered and have now been thoroughly investigated. We decided as reported earlier in favor of using two linear stages of 100 cm and 80 cm travel range, shown in Figure 2, to build a larger x-y scanning stage.

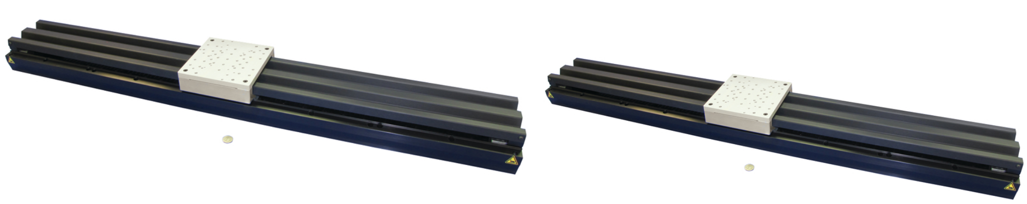

Figure 2: *Two linear stages by Newport, (a) 100 cm and (b) 80 cm, that would be used to construct a larger x-y transitional stage.*

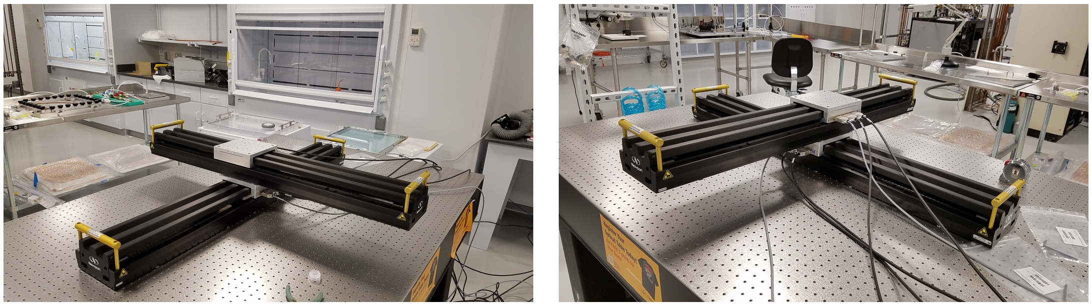

Figure 3: *Two new linear stages by Newport placed on top of each other on top of a 4'X 6' optical table inside the Temple University MPGD clean room facility.*

The GEM CCD scanner will be built on an already existing, new Newport optical table (6 ft x 4 ft), which is located in Temple University's Micro-Pattern Gas Detector (MPGD) clean room facility. Both linear stages were ordered and arrived recently at Temple University. Figure 3 shows both stages placed on the optical table inside the MPGD clean room facility.

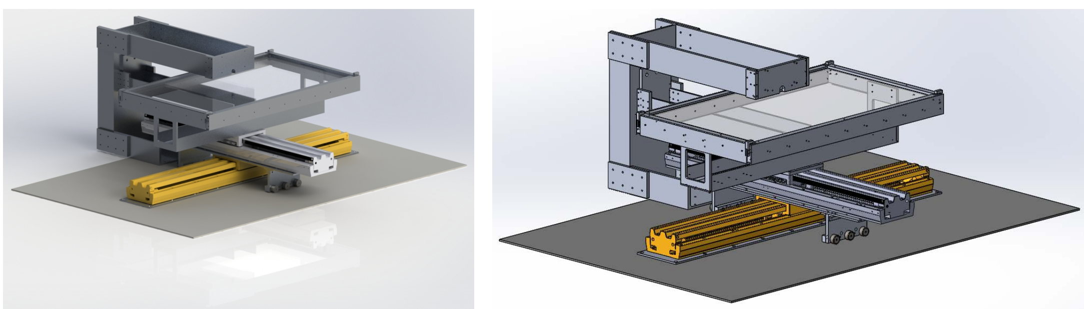

Figure 4: *3D views of the CCD scanning setup showing at the bottom both Newport linear stages.*

The design of a new scanning setup supporting a large GEM foil, CCD camera support and lighting system has been completed by our new mechanical engineer James Wilhelmi. Figure 4 shows an overview of this design. Figure 5 shows Solidworks simulations of the deflection of the supporting glass plates as a function of the actual glass thickness. A thickness of 0.5" ensures that the deflection stays well below 100 µm. All drawings have been submitted to our local machine shop. We do expect to have all parts in place by the end of July followed by the assembly and full commissioning of the new CCD scanner in fall 2016. The functionality of the linear stages themselves have already been verified.

3) <u>Tech-Etch Triple-GEM Detector (40 cm x 40 cm)</u>

We are planning - as reported earlier - on building 3 triple-GEM detectors, which are based on the STAR FGT [5]. The FGT design was chosen to save both money and time. Temple University already has all of the tooling specific to the FGT design that is needed to build a triple-GEM

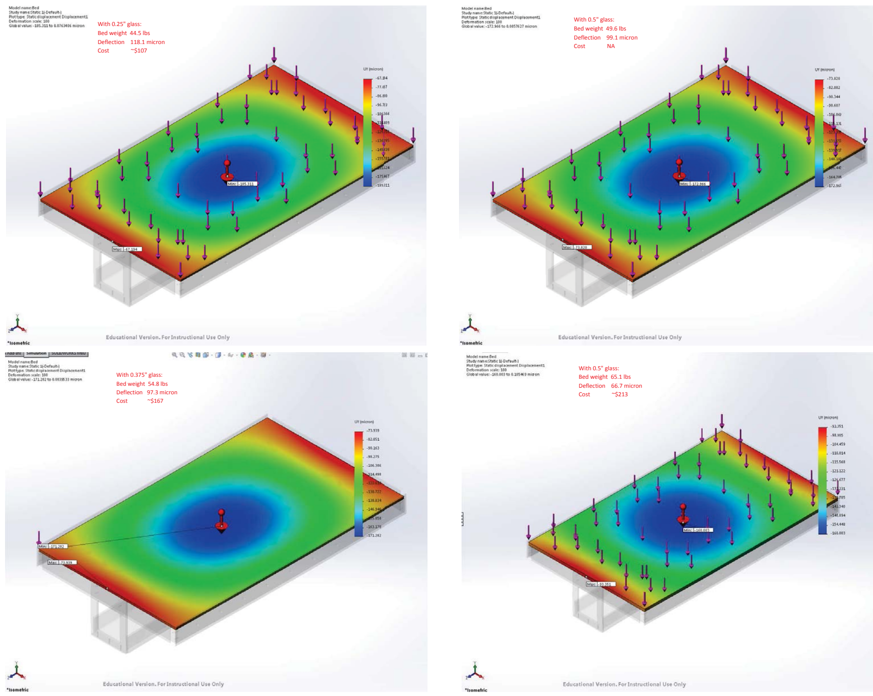

Figure 5: *Solidworks simulations of the deflection of the CCD scanner glass plate support.*

detector. This includes a nitrogen enclosure for leakage current testing, a stretching rig for gluing the foils, a design for the HV foil, frame design, readout board design, and soldering station. Those items are all located and already inside our MPGD clean room facility. Figure 6 shows the electrical test setup for GEM foil measurements and the stretching jig inside the MPGD clean room facility.

All essential components have been ordered and received which include:

- 9 40 cm x 40 cm single-mask GEM foils
- 3 HV foils
- 3 readout foils
- Multi-pin connectors
- Mylar pressure enclosure foils
- Assembly frames

Figure 7 shows one frame and close-up view of the location of HV connectors for each of the 9 X 3 segmented GEM foil sides and 3 X 3 unsegmented sides. All frames were machined by Circuit Connect Inc. from FR4 base material based on our drawings as shown in Figure 8 for one of the frames including all dimensions. Professor Bernd Surrow had prior good experience with this company. Our triple-GEM detector design requires 4 different frame types for a total of 6 frames per assembly.

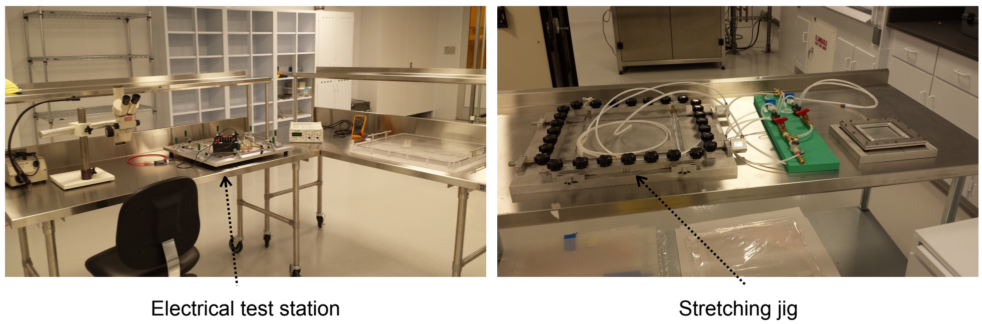

Figure 6: *Electrical test setup and stretching jig inside the MPGD clean room facility.*

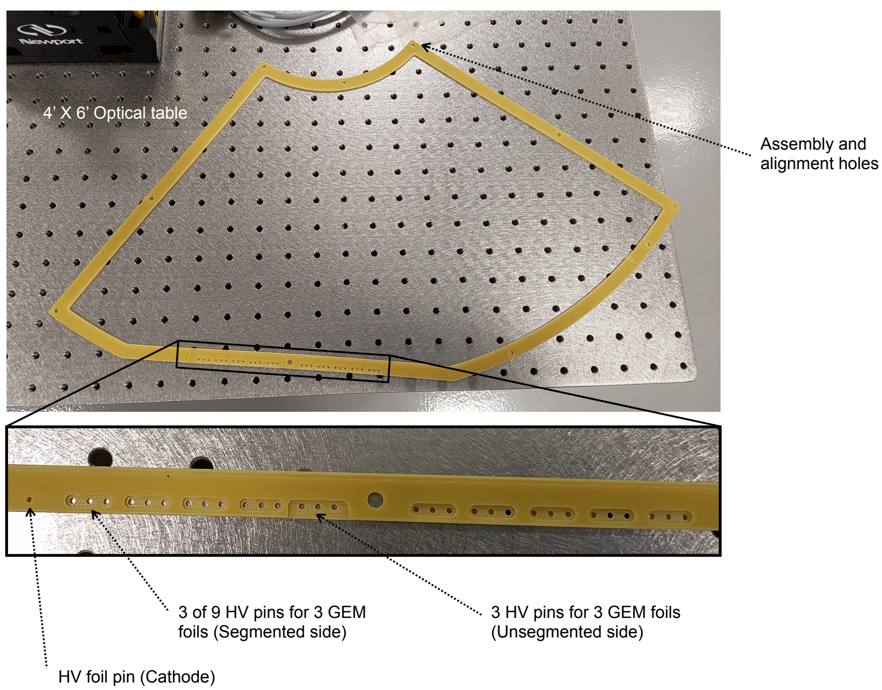

Figure 7: *Photograph of a triple-GEM frame and close-up view of HV pin locations.*

We are still waiting on the delivery of all Kapton spacer rings. Kapton was chosen as the base material after the vendor (Potomic Photonics) concluded that they would not be able to laser cut Apical material into rings due to issues between the Apical absorption frequency and their laser

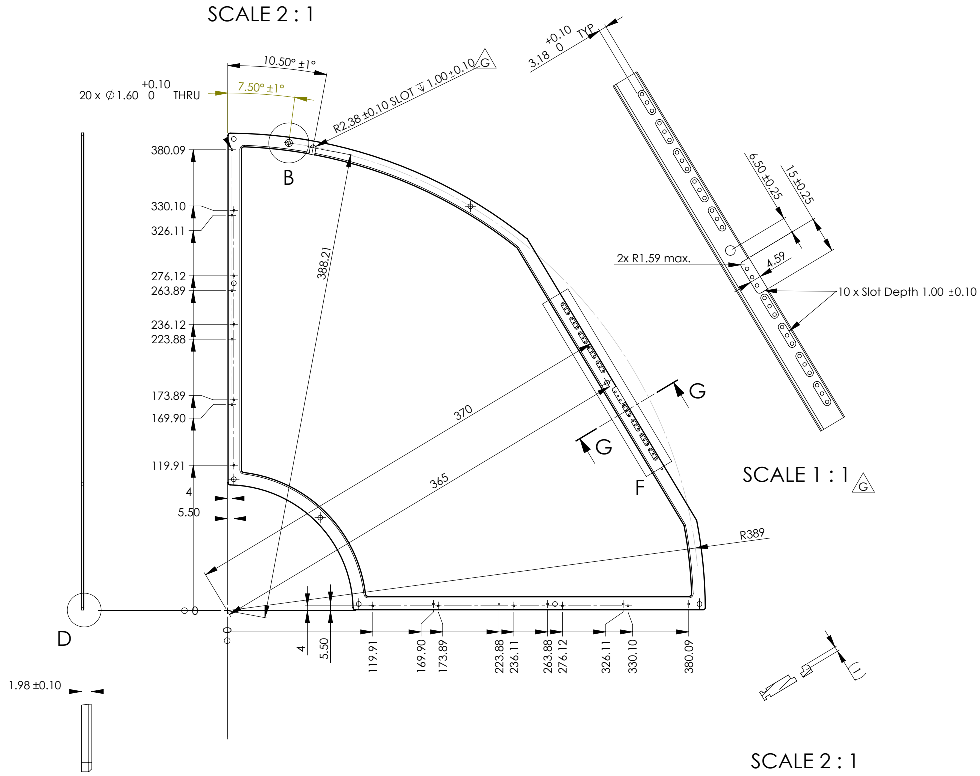

Figure 8: *Technical drawing of triple-GEM detector frame.*

used for cutting the material. As a result we placed an order for Kapton spacer rings. We do expect that we receive all Kapton rings during the summer. The majority of all GEM foils have been measured for their leakage current behavior. Satisfactory behavior up to 550V have been found with a leakage current to be less than 1nA. We are planning to scan those foils with our new scanning setup in fall 2016. The remaining time will be used to gain experience with the usage of an existing mechanical stretching fixture and soldering station for mounting HV pins to each GEM foil. This will be done in collaboration with a mechanical engineer at MIT Bates laboratory whom Professor Bernd Surrow has worked with before. Undergraduate students will assist in this process who are paid for in full by the College of Science and Technology at Temple University. We will also have them help work towards automating the leakage current measurements via LabView or Matlab. Having the leakage current measurements automated will be beneficial when wanting to study the time dependence of the leakage current. Multi-pin connectors providing the connection between each r-phi readout strip on the 2D readout foil and the chip-readout board will be soldered commercially by Proxy Inc. closely connected to MIT Bates laboratory. A visit to MIT Bates in July is planned to discuss this step and profit from their prior experience with Proxy Inc. .

We expect to have the first detectors assembled by the end of this year followed by cosmic-ray testing and X-ray scans. The cosmic-ray test-stand is fully commissioned including the APV

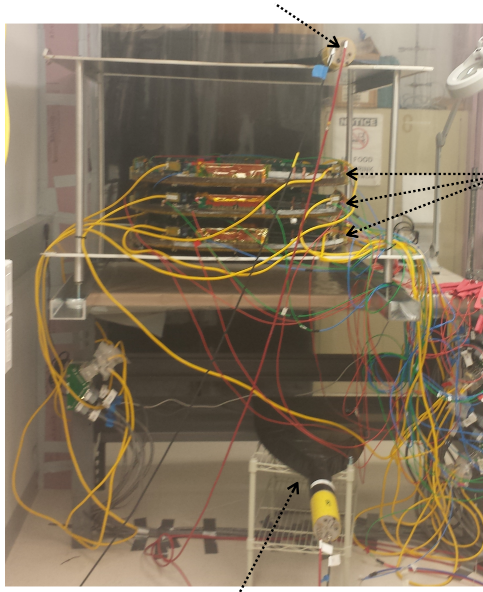

Figure 9: *Cosmic-ray test stand for triple-GEM detectors inside MPGD detector lab.*

DAQ readout system as shown in Figure 9. The X-ray gun is available. Its operation requires however a full Pb-enclosure which is requested in this proposal. The full gain scan characterization and subsequent publication is a critical step.

4) <u>Tech-Etch Triple-GEM Detector (10 cm x 10 cm)</u>

Several components are available. The full assembly and testing will be carried out over the next half year with the help of our new postdoc Dr. Amilkar Quintero.

5) <u>DREAM Chip Readout</u>

Given that the production of the APV chip, commonly used to readout information in GEM detectors, has now been stopped for some time, an alternative readout solution needs to be found. The DREAM chip, which is similar to the APV chip and is being used for CLAS12 [6], has been marked as a good substitute for the APV chip. Temple University has sent Saclay a triple-GEM detector, based on a STAR FGT quarter section, which used the APV chips for readout to be refitted with DREAM chips. CEA Saclay has successfully designed and built a transition card to connect a FGT quarter section to their current DREAM front-end-electronics. The newly de

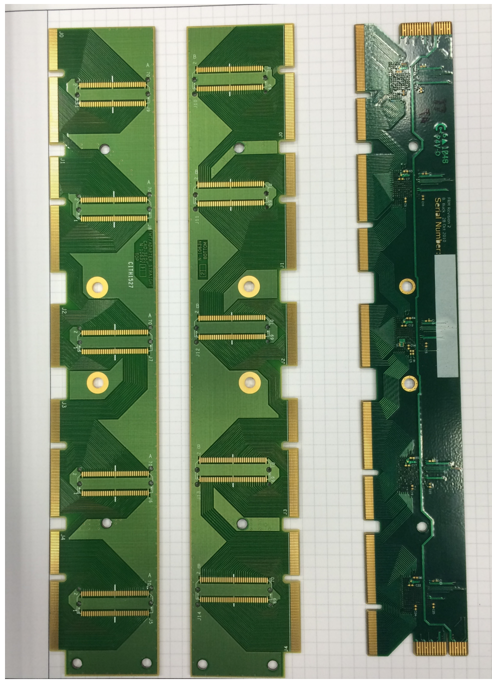

Figure 10: *Two FGT-DREAM cards (left) and one FGT-APV card (right).*

signed and fabricated FGT-DREAM cards will replace the current FGT-APV cards. Figure 10 shows the two FGT-DREAM cards on the left and one FGT-APV card on the right.

Once the detector was successfully refitted with the DREAM chips, the Saclay group began preliminary characterization of the detector via an ^{55}Fe source and cosmic-rays. The cosmic ray test bench can be seen in Figure 11. It should be noted that there is a slight mapping issue with the transition card and as such the results obtained so far are only preliminary and serve as an early look at the FGT performance using the DREAM chips. First results have been reported during the January 2016 status report presentation. Additional data were taken in the meantime. Our postdoc will engage in the analysis of these data sets including the correct mapping implementation.

6) Tech-Etch GEM Foil Development

The further GEM foil production at Tech-Etch will critically depend on larger orders placed by the nuclear and particle physics community. It was recently decided by the board of directors at Tech-Etch to pause the production of GEM foils until such a viable market becomes available. The LHC Experiments committee (LHCC) at CERN has recently urged the RD51 collaboration to emphasize the need for commercial fabrication. It was explicitly stated during a recent RD51 meeting that there should be enhanced efforts on industrialization including a statement that the

Figure 11: *FGT quarter section of the cosmic-ray test bench at Saclay. The blue cables connect the DREAM FEE to the FGT's transition card. The MicroMegas barrel can also be tested at the same time, as seen in the photograph.*

CERN management communicating to the LHC community such as ATLAS and CMS to consider placing orders outside CERN. This is certainly a critical step which the Tech-Etch management is waiting for. The fabrication of 2D readout foils and HV foils will continue at Tech-Etch.

What was not achieved, why not, and what will be done to correct?

All activities have been started. Several are delayed due to the availability of FY16 funding only in spring 2016.

Future

What is planned for the next funding cycle and beyond? How, if at all, is this planning different from the original plan?

Post-Doc

With the recent promotion of Dr. Matt Posik to Assistant Research Professor, his time able to be allotted to the EIC R&D program has been reduced (~50%). His remaining research commitment will be devoted to physics analysis at RHIC with the STAR experiment. Our new postdoc, Dr. Amilkar Quintero, will be trained by Dr. Matt Posik. He would be 50% dedicated to the EIC R&D program and 50% supported by Professor Surrow's DOE research grant. This work sharing allows the continuation of our R&D efforts.

Commercialization of Large GEM Foils

The most critical item that needs funding is the continuing development of commercially available large area GEM foils from Tech-Etch. These foils will not only play a vital role in EIC GEM tracking R&D, but the entire nuclear and particle physics community.

We plan on ordering scaled down EIC GEM foils from Tech-Etch / CERN that are on the order of 50 cm long. This will allow us to further characterize larger foils and begin building our EIC tracker prototype. This program takes us beyond our current generic R&D program and is discussed in the common eRD3/eRD6 report.

Construction of 40 cm x 40 cm Triple GEM Detector

After the construction of the Tech-Etch single-mask triple-GEM detector, we plan on using our already existing cosmic ray test setup to characterize the gain and performance of the detectors. We would then like to repeat these tests using our mini X-ray tube, however to do this we would need to purchase material to build a safety enclosure complete with an interlock system that will house our mini X-ray tube. We are currently working with Temple University EHRS to get more details on the required safety measures needed.

In addition to using the mini X-ray tube, we would like to purchase an ^{55}Fe source to map the gain of the detector as a function of position. These gains can then be correlated to foil hole uniformity that we obtained via our optical scanning of the individual foils. The accumulation of these studies should provide a clear determination of the Tech-Etch foil and CERN foil quality. It should be mad clear that there is no study on the CERN foil uniformity worldwide at such detail. Recent concerns have been raised of gain non-uniformity of large GEM foils produced at CERN. Our R&D program addresses exactly these issues. A subsequent 2nd NIM publication will complete this effort. Additionally we would also like to study various clustering methods.

GEM CCD Scanner Upgrade

The main focus is placed on the machining of parts, the assembly of the CCD scanner and the subsequent commissioning. A new CCD camera still needs to be purchased for our new CCD scanner.

Barrel MicroMegas R&D Program

Past

What was planned for this period?

In FY16, we had planned to carry out R&D efforts on the DREAM chip application to GEM detectors and 2D curved resistive MicroMegas prototype detectors: this technology has the clear advantage of minimizing the amount of material with respect to two 1D detectors.

What was achieved?

During this period the Saclay group was able to successfully design, build and test a transition card to connect a FGT quarter section triple-GEM detector to their current DREAM fron-end-electronics. To connect the FGT to the DREAM electronics, a passive transition card was build to connect the 2 “super-connectors” of one FGT quarter section to the MEC8 connectors used with the DREAM front end electronics. This FGT-DREAM card replaces the FGT-APV cards and allows the detector to readout using the DREAM chips rather than the APV chips. In addition to the GEM readout electronics work, the Saclay group has also continued further cosmic ray testing of their 1D MicroMegas barrel detector.

What was not achieved, why not, and what will be done to correct?

The delay in FY16 R&D funding delayed the process of the 2D Micro-meags R&D work. We are hopeful to continue this effort now over the next six months.

Future

What is planned for the next funding cycle and beyond? How, if at all, is this planning different from the original plan?

2D MicroMegas Detector

With the success of the two 1D MicroMegas detectors presented in the last progress report, we would like to continue the development of the cylindrical MicroMegas detector by building a large 2D curved resistive MicroMegas detector.

What are the critical issues?

The remaining part of the eRD3 general R&D program is focusing on its completion without adding any new R&D items followed by a transition to a prototyping and EIC detector design phase in preparation of the DOE Critical Decision process which holds for both the triple-GEM and MicroMegas activities. The highest priority is the postdoc support, needed to complete our generic R&D program. We expect to have our generic R&D program completed by 2018.

Manpower

One postdoc was supported at 100% shared between Dr. Matt Posik (~50%) and Dr. Amikar Quintero (~50%) to allow both to engage in hardware and physics analysis activities.

External Funding

Both groups, Temple University and Saclay did not receive any other grant funding in support of the actual R&D program discussed here. However, it should be emphasized that both institutions provided substantial facility support and the support of manpower such as a new mechanical engineer at Temple University and the support of undergraduate students.

Budget request

The main items for the budget request for FY17 are as follows:

- 1 postdoctoral research associate (continuing) - **Highest priority**
- Domestic travel (BNL / MIT / FIT / JLAB / UVA): $8,250
- International travel (Saclay / IEEE Conference): $5,600
- Material (Triple-GEM assembly): $2,500
- Equipment (MM assembly at Saclay ($12,000) / X-ray enclosure ($10,000)): $22,000

On-campus overhead rate: 56%.

The full budget breakdown for a total requested amount is shown below in Table 1 displaying the fractional breakdown by category with the largest amount of about 66% referring to the postdoc support as the highest priority.

DOE EIC R&D / eRD3 - Dr. Bernd Surrow (PI) (Temple University)	
	FY 2017
PERSONNEL	
Post Docs	$56,368
Fringe Benefits	
29.9% on Post Doc	$16,854
Total Personnel	$73,222
Travel - Domestic	$8,250
Travel - International	$5,600
Material	$2,500
Equipment	$22,000
OTHER:	
Total Direct Costs	$111,572
Modified Total Direct Costs (MTDC)	$89,572
F&A: On-Campus Overhead 56%	$50,160
Total Project Costs	$161,732

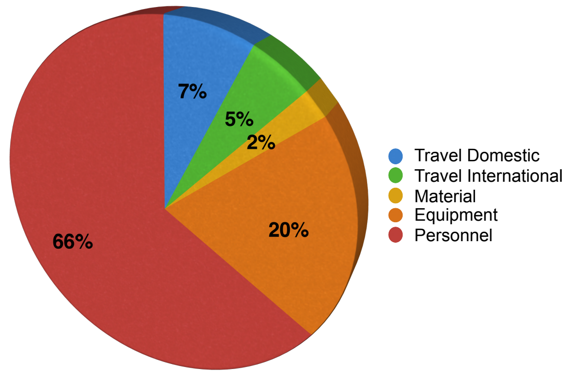

Table 1: *FY16 budget breakdown for eRD3 EIC R&D program.*

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[1] A. Accardi et al., Report on 'Electron Ion Collider: The Next QCD Frontier-Understanding the glue that binds us all', arXiv 1212.1701 (2012)

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[6] https://www.jlab.org/Hall-B/clas12-web/